Quarterly Progress Report, May 1994 - July 1994
ONR Contract Number N00014-93-1-1235
Drew McDermott, PI
Yale University Department of Computer Science

Our work on perception-based planning and execution continues:

- In this quarter, we extended our visual servoing capabilities to include operations such as visual alignment along an axis, and full six-degree-of-freedom relative positioning. We demonstrated the use of alignment by programming the system to place a screwdriver onto a screw. As with all other visual control operations, these are calibration-insensitive. We also demonstrated vision-based robot control. We have developed a small piloting program that permits a user to guide the robot using visual tracking. The user can point at objects such as a door or window, or simple features such as corners or other areas with high contrast, and instruct the robot to home on those features while performing obstacle avoidance. We have also demonstrated some early results on selecting features to track automatically.

- We have been running experiments to test our object-recognition algorithms. We generated 75 images by dropping two-dimensional objects into random cluttered arrangements on a table top. Fifty of the images contained the target, almost always occluded; 25 did not contain it. We ran the algorithm on all 75 images. When the object was present, the algorithm produced an average of 2.16 feasible interpretations, which included the actual object whenever it was present and less than 90% occluded. When the object was absent, the algorithm produced less than one feasible interpretation on average. The goal of the algorithm is to filter the edge sets from the raw image so that a detailed matcher has to be called only once or twice per image. So far, it appears to be completely successful. The bogus interpretations the algorithm finds can be quickly rejected by slightly more sophisticated matching algorithms. The results will be reported in forthcoming paper by Tagare and McDermott.

- Our planning work focused on the redesign of the XFRM-ML notation for expressing plan transformations; and on reorganizing our declarative planner. XFRM-ML a PROLOG-like language that comprises PROLOG primitives, a LISP interface, and a set of built-in predicates for temporal reasoning, as well as predicates on task networks and plans. These built-in predicates reconstruct—when necessary—the state of the robot and its environment, the status of tasks (succeeded, failed, active, etc.), and the value of program variables and data structures at arbitrary points in a projected scenario.

  Using XFRM-ML, we can characterize important kinds of execution failures of robot plans that cannot be represented in other planning representations. XFRM-ML also allows for concisely coding plan revision methods for reactive plans with complex control structures. We gain the necessary expressiveness of XFRM-ML by not restricting the representation to the predicted effects of plan execution on the world, but in addition representing how the plan interpretation changes the state of the agent, and how plan interpretation is connected to change in the environment. Just predicting the effects of the plan does not suffice to diagnose plan failures caused by overlooking objects or faulty world models. Based on the XFRM-ML representation, our planner can infer answers to questions like, has a particular subplan been executed?, why (not)?, etc.

Activities:

Greg Hager organized a workshop on Visual servoing at the International Conference on Robotics and Automation, in May

Greg Hager gave a talk at the DLR Oberpfaffenhoffen in Germany

Drew McDermott gave an invited talk entitled, "The Other Problem with Classical Planning," at the Second International Conf. on AI Planning Systems, Chicago, June 13

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A
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Publications:

Michael Beetz and Drew McDermott. Improving Robot Plans during Their Execution. In Kris Hammond (ed.), *Proc. Second Int. Conf. on AI Planning Systems,* San Mateo: Morgan Kaufmann 1994

Sean Engelson. Passive Map Learning and Visual Place Recognition. Yale Computer Science Department Technical Report 1032. (Ph. D. thesis)

Greg Hager. Real-Time Feature Tracking and Projective Invariance as a Basis for Hand-Eye Coordination. In *Proc. IEEE Conf. on Computer Vision and Image Processing (CVPR)*, pages 533–539. IEEE Computer Society Press, June 1994.

Greg Hager, W. Chang, and A. Steven Morse. Robot Feedback Control Based on Stereo Vision: Towards Calibration-Free Hand-Eye Coordination (with W. Chang and A.S. Morse). In *Proc. IEEE Int. Conf. on Robotics and Automation*, pages 2850–2856. IEEE Computer Society Press, May 1994.

Greg Hager, W. Chang, and A. Steven Morse. Robot Feedback Control Based on Stereo Vision: Towards Calibration-Free Hand-Eye Coordination. To appear, *IEEE Control Systems Magazine,* Feb. 1995.

Aage Bendiksen and Greg Hager. A Vision-Based Grasping System for Unfamiliar Planar Objects . In *Proc. IEEE Int. Conf. on Robotics and Automation*, pages 2844–2849. IEEE Computer Society Press, May 1994.

Greg Hager and Gerhard Grunwald. Feature-Based Visual Servoing and its Application to Telerobotics In *Proc. IEEE Int. Conf. on Robotics and Automation*

Greg Hager. Task-Directed Computation of Qualitative Decisions from Sensor Data. To appear in the IEEE Transactions on Robotics and Automation.

Hemant Tagare and Drew McDermott. Model-Based Edge Selection for 2-D Object Recognition. Yale Computer Science Department Technical Report 1044.

Personnel Support:

- *Graduate Students (full time):* Michael Beetz, Aage Bendiksen, Kentaro Toyama
- *Graduate Students (part time):* Wenhong Zhu
- *Post-doc (half-time):* Hemant Tagare
- *Secretary (half-time):* Paula Murano

Expenditures:

The accompanying table shows the figures for expenditures to date, including amounts committed but not actually spent.

Overall Status and Plans:

We are producing a lot of stuff, but we are running a deficit. We are in the process of applying for supplementary funds under various programs.

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
NON-LADDER ACAD $ RES APPTS	44,765	7,730.65	8,920.02	16,650.67	28,114.33
FACULTY SUMMER COMP	55,084	38,000.00	.00	38,000.00	17,084.00
MANAGERIAL & PROFESSIONAL	9,905	10,115.45	10,341.47	20,456.92	-10,551.92
STUDENT ASST.	21,310	15,468.44	25,779.54	41,247.98	-19,937.98
EMP. BENEFITS	36,208	18,490.91	6,263.75	24,754.66	11,453.34
D/P SUPPLIES	0	-220.00	220.00	.00	.00
MINOR EQUIPMENT	0	-249.95	252.95	3.00	-3.00
D/P SVS.	3,076	10,000.00	12,754.00	22,754.00	-19,678.00
FREIGHT & TRANSPORTATION	0	70.25	128.98	199.23	-199.23
PHOTOCOPYING	795	7.46	1,192.18	1,199.64	-404.64

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
PRINTING-PUBLICATIONS	0	.00	1,000.00	1,000.00	-1,000.00
MISC. SERVICES	0		36.00	36.00	-36.00
TRAVEL (DOMESTIC)	0	2,254.55	2,773.01	5,027.56	-5,027.56
CONFERENCE & SEMINAR FEES		150.00		150.00	-150.00
OFFICE SUPPLIES	489		86.96	86.96	402.04
TUITION REMISSION	2,839	6,286.62	16,880.00	23,166.62	-20,327.62
PERIODICALS, BOOKS	0	156.00	219.35	375.35	-375.35
POSTAGE	0	.00	354.11	354.11	-354.11
HEALTH INS.	0	2,088.00	896.00	2,984.00	-2,984.00
TELEPHONE TOLLS	495	149.62	135.04	284.66	210.34
DATA PROC. EQUIPMENT	15,007	3,144.00	4,302.20	7,446.20	7,560.80
INDIRECT (OVERHEAD 64.0%)	110,162	66,695.26	45,754.82	112,450.08	-2,288.08
TOTAL:	300,135	180,337.26	138,429.38	318.766.64	-18,631.64
	SPENDING BALANCE AVAILABLE AS OF August 1, 1994:				-18,631.64